RULES FOR CLASSIFICATION

Ships

Edition October 2015
Amended July 2017

Part 3 Hull
Chapter 9 Fatigue
FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

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Any comments may be sent by e-mail to rules@dnvgl.com

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CHANGES – CURRENT

This document supersedes the October 2015 edition of DNVGL-RU-SHIP Pt.3 Ch.9. Changes in this document are highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

Amendments July 2017

• Sec.1 General
  — Sec.1 [1.2]: The guidance note is modified.
  — Sec.1 Symbols and Sec.4 [4.2]: $T_{c25}$ modified to $T_{C,25}$ to align with DNVGL-CG-0129.

Amendments July 2016

• Sec.4 Fatigue strength calculations
  — Sec.4 [2] Springing and whipping have been added in the description.

Amendments January 2016

• General
  — Only editorial corrections have been made.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.
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SECTION 1 GENERAL

Symbols

For symbols not defined in this section, see Ch.1 Sec.4.

\( \alpha \) = fraction of time at sea for a specific loading condition
\( \beta_s \) = fraction of maximum permissible still water bending moment for a specific loading condition
\( D \) = fatigue damage calculated by Palmgren-Miner rule
\( f_c \) = scantling approach factor
\( f_w \) = post-weld treatment factor
\( M_{sw,\text{min}} \) = minimum still water bending moment in kNm
\( M_{sw-h,\text{FLS}} \) = still water hogging moment in kNm, to be used in the fatigue assessment
\( M_{sw-s,\text{FLS}} \) = still water sagging moment in kNm, to be used in the fatigue assessment
\( T_C \) = total time in corrosive environment
\( T_{C,25} \) = time in corrosive environment during \( T_D = 25 \) years
\( T_D \) = minimum design life to be taken as 25 years
\( T_{DF} \) = design fatigue life specified by the designer, but not to be taken less than 25 years
\( T_F \) = calculated fatigue life
\( CFD \) = Computational Fluid Dynamics, i.e. hydrodynamic calculations
\( FAT X \) = S-N curve where \( X \) corresponds to stress range value in N/mm\(^2\) at \( 2 \cdot 10^6 \) cycles.

1 Application, scope and acceptance criteria

1.1 Introduction

This chapter provides fatigue strength requirements for welds and free plate edges.

The fatigue assessment of the hull structure is based on high cycle wave induced loads, design S-N curves and Palmgren-Miner method for linear fatigue damage accumulation.

The structural details required for fatigue strength assessment are determined with consideration of ship type experience, probability of fatigue cracking and consequence of failure.

1.2 Application

This chapter is applicable to:

— ships having rule length \( L \) of 150 m or greater
— ship hulls and outfitting details made of steel
— ships operating in world wide trade
— dependent on ship type as defined in Pt.5 and structural arrangement, fatigue assessment may also be required for ships with rule length \( L \) less than 150 m.

Guidance note:

World wide trade is defined in the Society’s document DNVGL-CG-0130 Wave load analysis and includes periods of operation in harsh environment such as the North Atlantic and the North Pacific.

---end---of---guidance---note---
1.3 Assessment scope and extent
The scope and extent of fatigue assessment is defined in:
— Sec.2 [2] for main class
— Pt.5 for specific ship types and designs
— Pt.6 Ch.1 for additional class notations.

1.4 Acceptance criteria
The design fatigue life, $T_{DF}$, shall be 25 years, unless a higher value is specified by the designer. The calculated fatigue life, $T_F$, shall comply with the following requirement:

$$T_F \geq T_{DF}$$

To achieve a calculated fatigue life being larger or equal to the design fatigue life, the calculated cumulative fatigue damage, $D$, shall be less than or equal to 1.0 during the design fatigue life.

1.5 Supporting documents
The Society’s document DNVGL-CG-0129 *Fatigue assessment of ship structures* supports the rules in this chapter and provides detailed procedures for fatigue strength calculations.
For specific ship types, see also the Society’s documents:
— #to-be-resolved *Finite element analysis*
— DNVGL-CG-0130 *Wave load analysis*.
SECTION 2 MAIN CLASS REQUIREMENTS

1 Longitudinal stiffeners
Longitudinal end connections at frames and transverse bulkheads within 0.5 L amidships (from aft quarter length to forward quarter length) shall be assessed based on prescriptive fatigue assessment.

2 Other details
Fatigue assessment of other details subject to high longitudinal stresses within 0.5 L amidships may be required on a case-by-case basis.

Guidance note:
Examples of details with high longitudinal stresses caused by structural discontinuities:
— moonpool/large openings
— crane foundations
— foundation for heavy units
— hatch coaming ends
— end of superstructure.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
SECTION 3 METHODOLOGY

1 Principle
The fatigue strength for critical details shall be assessed by fatigue calculation. The scope and extent of fatigue assessment are based on in service experience, detail design and the assumption of satisfactory workmanship.

2 Workmanship
As a minimum, structural fabrication shall be carried out in accordance with Part A of IACS Recommendation No. 47, Shipbuilding and Repair Quality Standard. Other standards like ISO 5817 may be accepted provided they are equivalent to or more stringent than IACS Recommendation No. 47. Based on ISO 5817 it is required that quality level B is used for critical areas and deck and bottom plating within 0.4L amidships of container ships and level C is used for other areas of container ships and for all other ship types. Manufacturing details of welded joints and free plate edges may be requested as part of the approval.

3 Detail design
The scope and extent of fatigue assessment may be reduced on a case-by-case basis if the design of a detail follows a detail design standard according to the Society’s document DNVGL-CG-0129 Fatigue assessment of ship structures or the Society’s class guidelines for the specific ship types. This does not apply to longitudinal end connections.

4 Fatigue assessment

4.1 Load components
Reference is made to Ch.4 for definition of rule based fatigue loads and the Society's document DNVGL-CG-0130 Wave load analysis for direct wave load assessment. Main global and local wave induced loads shall be included in the fatigue strength assessment.

4.2 Selection of methods
The wave induced loads shall be either prescriptively or directly calculated, and the stress components shall be either calculated by beam theory or FE analysis. Which method to be used is described in Sec.2 [2] for main class, Pt.5 for the specific ship types or Pt.6 for additional class notations.

The following methods for load application and stress assessment are relevant:
— prescriptive analysis with rule load
— component stochastic (spectral) analysis, with direct wave load application combined with analytical stress calculation
— FE analysis with hot spot models of welded details and local models for free plate edges integrated in the global model or in the partial ship model, with rule loads.

The loads can be applied to the FE model in the following ways:
— rule loads based on equivalent design waves (EDW), referred to as FE analysis
— directly calculated EDWs, for global FE analysis
— directly calculated pressures and accelerations, referred to as full stochastic (spectral) FE analysis.
SECTION 4 FATIGUE STRENGTH CALCULATIONS

Symbols
For symbols not defined in this section, see Ch.1 Sec.4.

1 Approach
The fatigue assessment is based on the following methods:
— Welded details: nominal or hot spot stress approach. In cases where the nominal stress approach can not be applied, the hot spot stress approach shall be used.
— Free plate edges: local stress approach.

2 Assumptions
The following assumptions and parameters are the basis for the fatigue strength calculations:

a) high cycle wave induced loads for the world wide trade including the effect of wave induced vibrations (springing and whipping)
b) design S-N curves with 97.5% probability of survival
c) Palmgren-Miner method
d) time in corrosive environment, $T_C$
e) the effect of corrosive environment on the S-N curve
f) fraction of time at sea, $f_0$
g) fraction of time, $\alpha$, in each loading condition
h) fraction of permissible still water bending, $\beta_s$, in each loading condition
i) draft in each loading condition
j) metacentric height, $GM$, in each loading condition
k) radius of gyration in roll, $k_r$, in each loading condition
l) straight line load histogram for the prescriptive loads and for directly calculated EDWs
m) net thickness approach.

Requirements related to some of the assumptions are outlined in [4].

Guidance note:
If the vessel is intended to operate in harsh wave environment during the whole design life time North Atlantic may be specified for 25 years design fatigue life. Alternatively, an increased fatigue life of 40 years in world wide may be specified.

3 Effects to be considered
In addition to the assumptions, the following effects need to be considered in the fatigue assessment:

a) mean stress effect
b) material factor
c) thickness effect
d) post-weld treatment factor
e) misalignment.

Limitations to post-weld treatment are given in [4.4].
4 Basis

4.1 Selection of S-N curves
For welded joints, the following S-N curves shall be used:
— S-N curve D (FAT 90) for the hot spot stress approach
— FAT class S-N curves corresponding to the nominal stress approach.
For free plate edges S-N curve FAT112-150, i.e. C1, C and B2 shall be used depending on the surface quality.

4.2 Effect of corrosive environment and corrosion protection
Structural details are regarded as protected against corrosive environment for most of the design life. The time in corrosive environment, $T_{C,25}$, during the minimum design life, $T_D$, is given in Table 1. The S-N curves mentioned in [4.1] can be used for both periods, but the damage estimate for the time in corrosive environment shall be multiplied by two.

Table 1 Time in corrosive environment, $T_{C,25}$, during, $T_D$=25 years

<table>
<thead>
<tr>
<th>Location of weld joint or structural detail</th>
<th>Time in corrosive environment, $T_{C,25}$ in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water ballast tank</td>
<td></td>
</tr>
<tr>
<td>Oil cargo tank</td>
<td></td>
</tr>
<tr>
<td>Lower part$^1$ of cargo hold for dry bulk cargo</td>
<td>5</td>
</tr>
<tr>
<td>Cargo hold for dry bulk cargo except lower part$^1$</td>
<td>2</td>
</tr>
<tr>
<td>Void spaces</td>
<td></td>
</tr>
<tr>
<td>Fuel oil tanks</td>
<td></td>
</tr>
<tr>
<td>Coffer dam</td>
<td></td>
</tr>
<tr>
<td>Dry cargo holds</td>
<td></td>
</tr>
<tr>
<td>Hull external surfaces</td>
<td></td>
</tr>
<tr>
<td>Other areas</td>
<td></td>
</tr>
</tbody>
</table>

1) Lower part including inner bottom and other structure with a height of 1.5 m above the inner bottom.

If a target design fatigue life, $T_{DF}$, is exceeding the minimum design life, $T_D$, the total time in corrosive environment, $T_C$, is estimated as:

$$T_C = T_{C,25} \frac{T_{DF}}{T_D}$$
4.3 Loading conditions

Fatigue analyses shall be carried out for the prevailing loading conditions representative for the intended operation. The following parameters are input to the fatigue calculation:

- fraction of the time in each loading condition, $\alpha$
- fraction of time at sea, $f_0$
- draft
- metacentric height, $GM$
- roll radius of gyration, $k_r$
- fraction, $\beta_s$, of the permissible still water bending moment $M_{sw-s}$ in sagging or $M_{sw-h}$ in hogging, which gives the still water bending moments, $M_{sw-s,FLS}$ and $M_{sw-h,FLS}$, respectively, to be used to estimate the mean stress effect.

Standard values are listed in Table 2, but values from the loading manual may be used when available.

**Table 2 Standard values for loading conditions to be used for the fatigue analysis**

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Tanker &lt; 150 m</th>
<th>Bulk carrier and dry cargo ship$^{(10)}$</th>
<th>MPV/general dry cargo ship$^{(12)}$</th>
<th>Container ship</th>
<th>Gas carrier</th>
<th>Ore carrier$^{(10)}$</th>
<th>Passenger ship$^{(7)}$</th>
<th>RO/RO$^{(7)}$</th>
<th>Others$^{(8)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$, loaded condition</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4$^{(11)}$</td>
<td>0.7/0.3$^{(1)}$</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$\alpha$, ballast/partial condition</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6$^{(11)}$</td>
<td>-</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$f_0$</td>
<td>0.85</td>
<td>0.85</td>
<td>0.8</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.90</td>
<td>0.85</td>
</tr>
<tr>
<td>Draft, loaded condition</td>
<td>$T_{SC}$</td>
<td>$T_{SC}$</td>
<td>$0.9T_{SC}$</td>
<td>$T_{Design}$ but not less than $0.8T_{SC}$</td>
<td>$T_{SC}$</td>
<td>$T_{SC}$</td>
<td>$T_{Design}$</td>
<td>$T_{Design}$</td>
<td>$T_{SC}$</td>
</tr>
<tr>
<td>Draft ballast/partial condition</td>
<td>$0.7T_{SC}$</td>
<td>$T_{BAL}^{(2)}$</td>
<td>$0.7T_{SC}$</td>
<td>-</td>
<td>$0.8T_{SC}^{(3)}$</td>
<td>$0.63T_{SC}^{(4,5)}$</td>
<td>$0.775T_{SC}^{(6)}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$k_r$, loaded condition</td>
<td>0.35$B$</td>
<td>0.35$B$</td>
<td>0.39$B$</td>
<td>0.39$B$</td>
<td>0.32$B$</td>
<td>0.25$B$</td>
<td>0.39$B$</td>
<td>0.39$B$</td>
<td>0.39$B$</td>
</tr>
<tr>
<td>$k_r$, ballast/partial condition</td>
<td>0.45$B$</td>
<td>0.45$B$</td>
<td>0.39$B$</td>
<td>0.39$B$</td>
<td>0.42$B$</td>
<td>0.35$B$</td>
<td>0.39$B$</td>
<td>0.39$B$</td>
<td>0.39$B$</td>
</tr>
<tr>
<td>$GM$, loaded condition</td>
<td>0.12$B$</td>
<td>0.12$B$</td>
<td>0.05$B$</td>
<td>0.04$B$ for $B&lt;32.2$</td>
<td>0.09$B$ for $B&gt;40$; linear in between</td>
<td>$0.06B^{(3,4)}$</td>
<td>$0.05B^{(5)}$</td>
<td>0.25$B$</td>
<td>0.02$B$</td>
</tr>
</tbody>
</table>
Fatigue

1. Two loading conditions, a minimum and maximum hogging condition, shall be checked separately. The lowest fatigue life from the two loading conditions is representative of the calculated fatigue life, $T_F$. For each loading condition, the ballast tank shall be considered as full (to the tank top) 70% and empty 30% of the time, and the fatigue damage shall be calculated as the sum of these two contributions.

2. Ballast condition, see Ch.1 Sec.4 [3.1.6], shall be taken from the loading manual.


5. C-tanks.

6. Membrane.

7. Values used when Global FE is required by Pt.5. Prescriptive assessment of longitudinal end connections is not required for passenger vessels.

8. Other ships need to be specifically considered.

9. $M_{sw, min}$ is a minimum design hogging moment taken from the loading manual. If $M_{sw, min}$ is larger (hogging positive) than $0.1M_{sw-h}$, then $M_{sw, min}$ shall replace $0.1M_{sw-h}$.

10. Applicable for ore carrier, bulk carrier and dry cargo ships except MPV/general dry cargo ships having a long centre cargo hold. Internal pressures, including dry cargo mass and density, according to Pt.5 Ch.1 Sec.2 [3].

11. For each loading condition, the ballast tank shall be considered as full (to the tank top) 30% and empty 70% of the time, and the fatigue damage shall be calculated as the sum of these two contributions for each loading condition. In the partial condition with empty ballast tanks, bulk cargo pressures should be considered for the hold filled with 70% of the maximum cargo mass and a density of $\rho_c = 1.0$.

12. Applicable for MPV/general dry cargo ships having a long centre cargo hold as defined in Pt.5 Ch.1 Sec.1 [3.1].
4.4 Weld profiling and toe grinding

In case of weld profiling and toe grinding the post weld treatment factor may be accepted for details assessed by FE analysis and under the following conditions:

— post-weld treatment is not applicable to longitudinal end connections
— post-weld treatment is only applicable for high cycle fatigue
— treatment of inter-bead toes is required for large multi-pass welds
— the hot spot is protected from corrosive environment
— full penetration welds, or partial penetration welds with a maximum root face of 1/3 of the gross thickness are applied. The benefit of post-weld treatment may be considered for welds with larger root face or fillet welds, if it is demonstrated that the fatigue life of the weld root is also satisfying the acceptance criteria
— the initial fatigue life prior to the post-weld treatment shall be minimum 17 years, or 25 years in a cargo hold where mechanical damage due to loading/unloading operations are likely to occur
— documentation of the quality control procedures shall be submitted for review. The builder shall also provide the list of details and their locations on the ship, for which the post-weld treatment has been applied.
SECTION 5 SPECIAL CONSIDERATION

1 General

Other procedures than those given in the Society's document DNVGL-CG0129 Fatigue assessment of ship structure or the Society's class guideline for the specific ship types may be accepted or required on a case-by-case basis.

The following may need to be considered:

— the Society may request additional details to be assessed
— for innovative hull designs, the required scope of fatigue evaluation will be specially considered
— for certain structural details:
  — other load effects than the wave induced stresses may need to be considered
  — a reduced permissible cumulative fatigue damage may be required based on consideration of criticality
  — additional verification by fracture mechanics may be required
— the Society may require directly calculated loads or the use of FE models when the prescriptive rules (loads or stress formulations) are not regarded applicable for the specific structure or design
— directly calculated loads and use of FE models may also serve as basis to obtain more accurate fatigue life prediction.
CHANGES – HISTORIC

July 2016 edition

Amendments July 2016

• Sec.4 Fatigue strength calculations
  — Sec.4 [2]: Springing and whipping have been added in the description.
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